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Chemistry: progress since 1860—reflections on chemistry and chemistry education triggered by reading Muspratt's Chemistry

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Abstract
This paper was inspired by the author's fortunate acquisition of a copy of an original copy of "Muspratt's Chemistry" that was published in 1860. This raised, for the author, interesting and significant issues regarding the chemistry content and its presentation in the context of chemistry and education today. The paper is presented in two parts: Part 1 explores the content, structure and gives reactions to and insights into the original publication, whereas Part 2 provides a focus on the developments in chemistry education as experienced by the author during almost 70 years of learning and teaching chemistry in schools and in teacher education in England. James Sheridan Muspratt (1821–1871) is best remembered for this publication which is fully entitled "Chemistry, theoretical, practical and analytical as applied and relating to Arts and Manufactures". This was developed during the period 1852–1860 and ran into several editions as well as being translated into German and Russian. Earlier he had done chemistry research with Liebig and Hofmann, and in 1848 he founded the Liverpool College of Chemistry. It is clear that he corresponded extensively with many of the leading nineteenth century chemists in the UK and Europe, many of whose names are still familiar with us today.

Keywords Muspratt's Chemistry 1860 · History of chemistry · Industrial chemistry · Chemistry education · Professional Reflection

Introduction

About two years ago I bought a copy of the two-volume publication "Muspratt's Chemistry" at a local auction. I was clearly the only chemist bidding. The volumes were only in fair condition, but were complete and contained 2022 pages. The full title is "*Chemistry, theoretical, practical and analytical as applied and relating to Arts and Manufactures*". (I understand that a version of this was first published around 1852–3 in about 40 parts each of 42 pages.) The present volumes presumably represent an updated/extended version of

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these. Google Books provides, free, digitised copies of a number of versions of the publication.) Browsing through the pages gave much pause for thought as to how much chemistry had changed by the time I came to study it at school and university in the 1950s and 60 s, but also how the emphasis in my O-level syllabus (1955) retained some of the 1860 flavour. When I was a student, the framework for education in chemistry and the organisational context of schools, colleges and universities in the UK were substantially different from today. Also, chemistry itself has undergone huge changes in terms of theory, practice and real-world applications. Two perspectives are explored in the parts into which the paper is divided:

> *Part 1. Reflections on Muspratt's Chemistry (1860)*—This provides a view of how chemistry was perceived at the time and explores some personal reactions to it from someone who graduated in chemistry just 100 years later.
> *Part 2. Reflections on Chemistry Education in the light of reading Muspratt's Chemistry (1860)*—From 1960 to the present day.

Since this paper was triggered by an 'accidental' encounter with an authoritative chemical text it is appropriate to give a brief outline of the author's professional journey. Having graduated in chemistry in 1960, he taught in secondary schools in England for nine years before moving into primary and secondary school teacher education in Manchester. The college became incorporated into Manchester Polytechnic in 1970 and subsequently merged with five other teacher education colleges in Manchester. He became Head of the Department of Sciences Education in 1978 and retired in 2002. In 1992 Manchester Polytechnic was re-designated Manchester Metropolitan University.

Part 1: reflections on Muspratt's Chemistry (1860)

These books were clearly intended to be an authoritative text on the chemistry of the time, but what really mattered to the editor (Muspratt), were the practical details and economic rewards from producing useful chemicals on an industrial scale. Presumably he would not have expected anyone to read the books from cover to cover—the topics are presented in alphabetical order—but to use the articles on a 'need to know' basis as an authoritative source of up-to-date information on current practice in the topics covered. Nowadays, chemists and engineers with specialist interests will have internet links, access to specialised research journals, expert surveys, data-books and conferences. They will usually also have successfully completed a recognised educational programme that provides them with an initial theoretical basis, an introduction to current techniques and practise in their subject and the point of entry to their profession.

A number of features of the Muspratt's Chemistry that seemed to me particularly interesting are discussed in more detail in subsequent sections. these are:

A. General perceptions of the two volumes.
B. Muspratt's intellectual chemistry environment.
C. Terminology (Heat and energy.)
D. Basic skills, ideas and tabulated data.
E. Fuels and the materials of industry and commerce.
F. The minute detail in which industrial processes are discussed, together with an emphasis on commercial aspects. Developing concern for Health and Safety.

G. Processes in very early stages of development: (a) Electrometallurgy (b) Photography.
H. In conclusion.

General perceptions of the two volumes

It is not now immediately clear what was the intended readership of this massive compilation or what level of previous experience in chemical science and manufacture was being assumed of the readers. The publication aimed to be as detailed and comprehensive account as possible of the properties and production of commercially important chemicals and processes—and in the preface (Vol. 1) Muspratt apologises for its excessive length and detail, but opines that "*for those who are really desirous of useful practical information on any of the subjects discussed, will find in this very minuteness of detail the most valuable feature of the work*". It can probably best be classified as an encyclopaedic reference work or 'Dictionary of Chemical Industrial Practice' rather than a text-book for beginners. It is likely that it was found only in academic or industrial libraries and on the bookshelves of (rich) dedicated chemists. I would guess that the original print run would have been relatively modest and the cost of a copy very expensive. The publication ran to several editions in English and was also translated into German and Russian. (https://en.wikisource.org/wiki/Muspratt,_James_Sheridan_(DNB00.) Thus, it seems clear that the publication was held in high regard when it first appeared in print. Nowadays it provides interesting insights into the 'state' of chemistry at that time, the extant theories and the priority interests of chemical practitioners.

The first 30 unnumbered pages consist of etched portraits of well-known chemists of the time including their facsimile signatures. The contents are organised in alphabetical order from 'acetic acid' (on page 1) to 'ether' in Volume 1 and from 'fuel' to 'zinc' in Volume 2 with an extensive table of contents at the beginning of each volume.

The intellectual chemistry environment

The books were written very early in the development of what may be termed 'Modern Chemistry. Indeed, this was only 60 years after the first introduction of the atomic theory by John Dalton in 1803 and 10 years **before** the first publication of the Periodic Table of Elements by Mendeleyev in 1869.

The names of 15 who are familiar to me, together with that of the editor Muspratt, are shown in the table below with their dates. Those with dates in bold were active at the time the book was published and, presumably were likely to be known by, and to have corresponded with, Muspratt.

Sheridan Muspratt (Editor)	**1821**	**1871**
Justus Liebig	**1803**	**1873**
August Wilhelm Hofmann	**1818**	**1892**
Robert Bunsen	**1811**	**1899**
Friedrich Wöhler	**1800**	**1882**
Joseph Priestley	1733	1804
Antoine-Laurent de Lavoisier	1743	1794
Thomas Graham	**1805**	**1869**
Joseph Louis Gay-Lussac	1778	1850
Humphry Davy	1778	1829

Joseph Black	1728	1799
Lyon Playfair	**1818**	**1898**
Michael Faraday	**1791**	**1867**
Jean-Baptiste Dumas	**1800**	**1884**
Jöns Jacob Berzelius	1771	1848
John Dalton	1776	1844

Thus, there was a significant group of eminent and active chemists whose ideas and writings would have influenced Muspratt and he would also have been aware of the work of those who had died earlier. All of the group seem to have been based in Britain and Europe, so it is interesting that he chose to include an evaluative supplement at the end of Volume 2 (pp. 1179–1186) by Prof. Horsford from America. These seven pages contain wide-ranging comments, additions and corrections and are indicative of a significant transatlantic science communication link at this time.

In view of such a wide-ranging group of prominent chemists it seems somewhat surprising that there is little direct reference to or explanation of developing ideas of elements, atoms, equivalent (atomic?) weights or even the use of a Bunsen burner and the beginnings of emission spectroscopy. To a chemist working in the late 20th or early twenty-first century the lack of an agreed set of coherent theoretical ideas and definitions of basic terminology in a major chemical text seem problematic (clearly in 1860 the framework would have been very different from current practice since even the existence of atoms and elements was then contended.)

It is interesting to note (Sutton 2019) "*In 1860* (The same year as Muspratt's publication.) *that a conference in Karlsruhe (Germany)- attended by Dimitri Mendeleev who was at that time funded (by Russia) to undertake advanced study at the University of Heidelberg—a major contributor to the conference was Stanislau Cannizzaro who delivered a ground breaking paper on atomic weights (now called relative atomic masses). This became a crucial step towards the periodic system.*

Some chemists claimed these 'weights' to be irrelevant or even denied the physical existence of atoms altogether. Others preferred a system based on an atomic weight of eight for oxygen, assuming that the formula of water was HO rather than H_2O. *At this conference Cannizzaro reviewed the ideas of his fellow countryman Amadeo Avogadro to support the* H_2O *formula and an atomic weight for oxygen of 16. During the 1860s opinion shifted in favour of this view.* Thus, the fact that neither Cannizzaro nor Avogadro appear on the list of chemists at the beginning of volume 1 may explain the consistent use of HO for the formula of water in this publication?

Terminology

The language used generally seems clear but sometimes interpretation is difficult. This can be exemplified again from the acetic acid section (Vol.1 p. 2) "*A solution of nitrate of silver is not clouded by free acetic acid; but it is troubled by saturating the free acid with ammonia.*" There seemed to be no obvious reason why the lack of reaction with silver nitrate should be included here, but—what is 'troubled' and what does 'troubled' mean? It is possible to speculate a number of possible interpretations. Perhaps it indicates a vigorous (bubbling/boiling) reaction or it may simply imply the neutralisation of the acid by the ammonia or something else.

Some key chemical terms clearly had not achieved their modern meanings and, possibly, not come into general use. In Vol.1 p. 67 a word equation for the fermentation of grape sugar is given as:

> “1 atom of dry grape sugar $C_{12}H_{12}O_{12}$ = 4 atoms of carbonic acid C_4O_8 + 2 atoms of alcohol $C_8H_{12}O_4$”

It is clear that the word ‘atom’ does not carry its current meaning, the combination of all the numbers in the formulae for ‘4 or 2 atoms’ would no longer be accepted and, it seems that here, the alcohol is represented as a ‘monohydrate’ otherwise the formula would not accord with that given earlier (C_4H_5O). A more modern formulation of the equation would be:

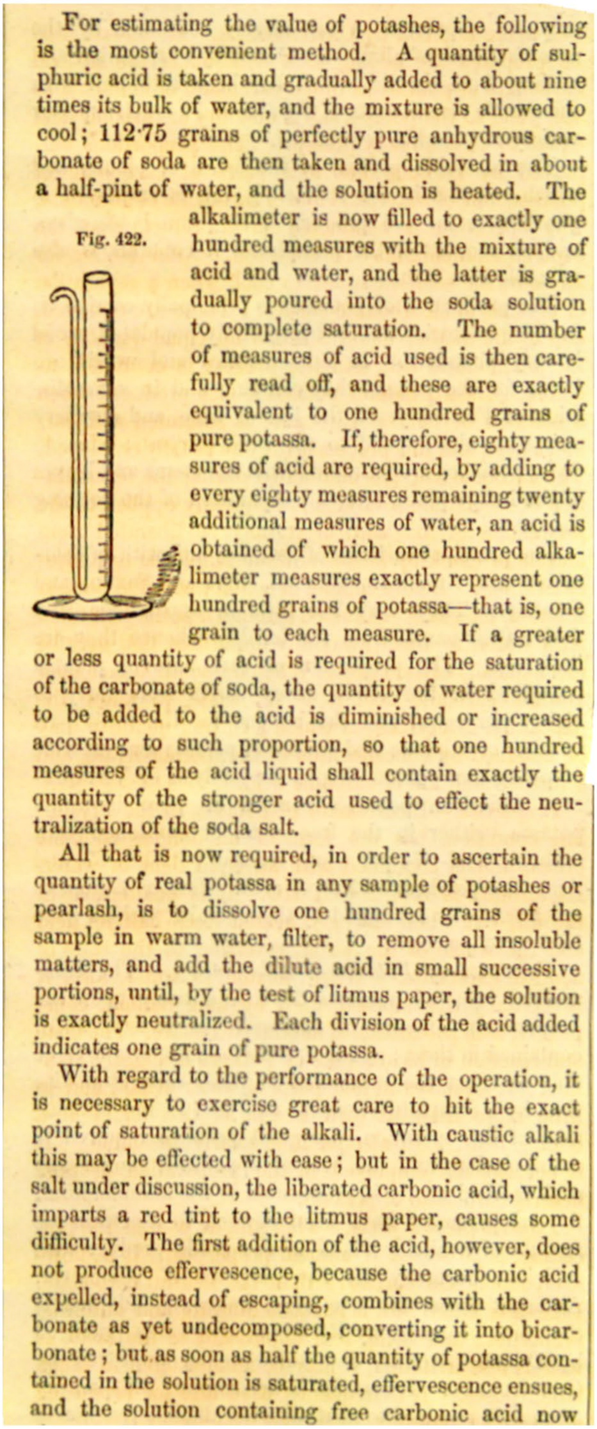
$$C_{12}H_{22}O_{11} + H_2O = 4C_2H_5OH + 4CO_2$$

Nowadays we would almost certainly use the term ‘molecule’ for the particles represented by the above formulae. I do not believe the word ‘molecule’ is used by Muspratt anywhere in this publication. According to www.etymonline.com/ the first use of Modern Latin ‘molecula’ in the modern scientific sense was by Amedeo Avogadro (1811). Possibly the word had not yet become common in England by 1860, indeed it may not have been seen as more useful/meaningful than ‘atom’—it could, in any case, not have included any idea as to how ‘atoms’ of elements’ join together to form molecules of new substances since atomic structures had not been discovered.

Another fundamental term that had not acquired its current meaning is ‘heat’. This had not yet been recognised as a form of energy. An explanation of the nature of heat termed ‘caloric’ is given in the section on ‘Fuels’ (Vol 2, pp. 1–177) *“Of the three imponderables (caloric, light and electricity) caloric is that which produces a sensation of heat in animal bodies. … … Caloric is self-repulsive and eminently destroys cohesion because it induces the particles of matter to separate to a greater or less distance, according to the amount of it which combines with them. … … the acknowledged sources of heat—namely the sun, electricity, chemical and mechanical action (extracted from p1-2)”* Following this is a discussion about thermometers (*heat-measurer),* the expansion of solids, liquids and gases; specific and latent heats and thermal conductivity.

No mention seems to be made of the heat given out when quantities of chemicals react in proportions defined by the chemical equation that would be equivalent to ΔH. Initially I did not register this as an omission until I realised that Hess’s Law had been published in 1840 (Holmyard and Palmer (1952)—a translation of Hess’s original paper is available at (https://www.chemteam.info/Chem-History/Hess-1840.html) It seems clear that Muspratt’s focus was not upon general chemistry ideas and theories that might have provided understanding and links betweendifferent sections of the his publication.

Box 1



For estimating the value of potashes, the following is the most convenient method. A quantity of sulphuric acid is taken and gradually added to about nine times its bulk of water, and the mixture is allowed to cool; 112·75 grains of perfectly pure anhydrous carbonate of soda are then taken and dissolved in about a half-pint of water, and the solution is heated. The alkalimeter is now filled to exactly one hundred measures with the mixture of acid and water, and the latter is gradually poured into the soda solution to complete saturation. The number of measures of acid used is then carefully read off, and these are exactly equivalent to one hundred grains of pure potassa. If, therefore, eighty measures of acid are required, by adding to every eighty measures remaining twenty additional measures of water, an acid is obtained of which one hundred alkalimeter measures exactly represent one hundred grains of potassa—that is, one grain to each measure. If a greater or less quantity of acid is required for the saturation of the carbonate of soda, the quantity of water required to be added to the acid is diminished or increased according to such proportion, so that one hundred measures of the acid liquid shall contain exactly the quantity of the stronger acid used to effect the neutralization of the soda salt.

Fig. 422.

All that is now required, in order to ascertain the quantity of real potassa in any sample of potashes or pearlash, is to dissolve one hundred grains of the sample in warm water, filter, to remove all insoluble matters, and add the dilute acid in small successive portions, until, by the test of litmus paper, the solution is exactly neutralized. Each division of the acid added indicates one grain of pure potassa.

With regard to the performance of the operation, it is necessary to exercise great care to hit the exact point of saturation of the alkali. With caustic alkali this may be effected with ease; but in the case of the salt under discussion, the liberated carbonic acid, which imparts a red tint to the litmus paper, causes some difficulty. The first addition of the acid, however, does not produce effervescence, because the carbonic acid expelled, instead of escaping, combines with the carbonate as yet undecomposed, converting it into bicarbonate; but as soon as half the quantity of potassa contained in the solution is saturated, effervescence ensues, and the solution containing free carbonic acid now

Basic skills and ideas and tabulated data

Clearly this is not intended as an introduction for beginners. However, there were no **general** details as to how basic laboratory procedures such as distillation, filtration and gravimetric or volumetric analyses are carried out and how calculations are performed—although some very specific examples are given in particular instances. The extract provided in Box 1, is taken from Vol 2, p. 730 and related specifically to the estimation of potassium carbonate, presumably in commercial samples. You may judge how clear the instructions are, but one might have expected that some general volumetric analytical procedures would have been found in a separate section of the text to which the reader could have been referred if appropriate. I was also surprised to find no reference to 'equivalent weights' in relation to the concentration of the solutions—although it seems to be implicit that 112.75 grains of anhydrous sodium carbonate are equivalent to 100 grains of potassium carbonate. This I fail to understand since, using today's formulations and atomic masses, the 100 grains of potassium carbonate (K_2CO_3) are equivalent to 72.5 grains of sodium carbonate (Na_2CO_3)! It appears that Muspratt has these ratios up-side down?

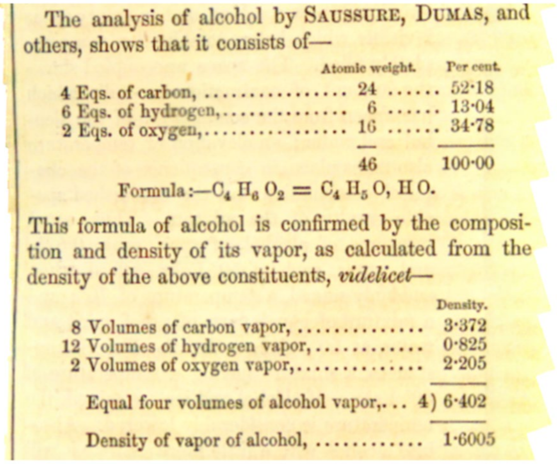
Despite the failure to agree on the arithmetic above the relatively sophisticated view if the two-stage reaction between a carbonate and acid, via the bicarbonate, is impressive.

I was not able to find a worked example as to how a chemical (empirical) formula can be derived from these and the percentage composition of a substance. As described above the process of doing volumetric calculations was explained on an individual basis in the appropriate section. The table for the formula of the 'monohydrate of acetic acid' (Vol.1 p. 2) is given below—although the numbers in brackets have been added:

Formula, $HO,C_4H_3O_3$

	Atomic Weight		Centesimal Quantities of each
4 equivalents of carbon…………. (4 × 6)	24	=	40
3 equivalents of hydrogen…….. (3 × 1)	3	=	5
3 equivalents of oxygen………… (3 × 8)	24	=	40
1 equivalent of water………………(1 + 8)	9	=	15
	60		**100**

Box 2: Analysis figures for alcohol. Muspratt Vol 1 p.54.



The analysis of alcohol by Saussure, Dumas, and others, shows that it consists of—

	Atomic weight.	Per cent.
4 Eqs. of carbon,	24	52·18
6 Eqs. of hydrogen,	6	13·04
2 Eqs. of oxygen,	16	34·78
	46	100·00

Formula:—$C_4 H_6 O_2 = C_4 H_5 O, H O$.

This formula of alcohol is confirmed by the composition and density of its vapor, as calculated from the density of the above constituents, *videlicet*—

	Density.
8 Volumes of carbon vapor,	3·372
12 Volumes of hydrogen vapor,	0·825
2 Volumes of oxygen vapor,	2·205
Equal four volumes of alcohol vapor,	4) 6·402
Density of vapor of alcohol,	1·6005

It is unclear how the percentage (centesimal) values were determined. The formula for water is given as HO which assumes that equivalent weights are equal to atomic weights. I am not aware of the existence of a monohydrate of acetic acid. Also, I would have anticipated that the equivalent weight of carbon would have been three, rather than six since I learned, and taught, at school that Eq.wt. = at.wt./Valency. i.e., for carbon = 12/4 = 3. (In the 1960s atomic weight rather than atomic mass was still the preferred term.) However, from Muspratt's perspective, carbon dioxide is formed from two equivalents (atoms) of oxygen and thus the equivalent weight of carbon from analysis figures would be 6. This, in modern terminology, would give carbon a valency of 2, but the concept of valency was not available in 1860. Where an element forms more than one compound with another particular element, e.g., CuO and Cu_2O then that element (copper) would have more than one equivalent weight—however, although both these copper oxides are recognised in the section on copper (Vol.1p528) the following equation is given:

$$2CuO\ (\text{Oxide of copper}) + 2Cu\ (\text{Copper}) = 2Cu_2O\ (\text{Suboxide of copper})$$

The accompanying text says *"From the formula it can be seen that two equivalents of the oxide afford as much oxygen as will convert two atoms of the metal into the suboxide…"* It seems therefore that, as already noted in section C the use of terms such as atoms and equivalents had relatively flexible meanings at the time. Probably we would use the term 'formula weight/mass'?

The section on acetic acid (Vol.1 p. 4) then develops to its production from alcohol by oxidation: (alcohol C_4H_5O to aldehyde C_4H_3O to acetic acid $C_4H_3O_3$.) Even these I find difficult to relate to the modern formulations which would be C_2H_6O; C_2H_4O and $C_2H_4O_2$ respectively. My 1960's and subsequent understandings of equivalent weights clearly do not give access to nineteenth century organic chemistry! An example of the analysis figures for alcohol (ethanol) are given in Box 2 and again, my chemistry background does not give me access to the calculation. In the first part it is difficult to see why Muspratt seems to double up the number of equivalents of all the elements involved to come up with the formula $C_4H_5O_2$ although this may have been needed to allow the separation of 'an atom/equivalent' of water HO. The lower part of Box 2 relating to the vapour density of alcohol, presumably must infer the Avogadro Hypothesis otherwise there is no basis for assuming the equal volumes of gases (even imaginary ones) contain the same number of particles; However:

- The statements do not seem to relate to equal volumes. To begin to make sense to me, the first line should read; '1 volume of carbon (C_8) vapour'; the second '1 volume of hydrogen (H_{12}) vapour' and the third '1 volume of oxygen (O_4) vapour'.
- The third line actually refers to '2 volumes of oxygen'—and even to be consistent with the upper part of Box 2—this should be '4 volumes of oxygen'.
- Assuming we now have vapour densities calculated from equal volumes of the imaginary particles in the list, it is far from clear why Muspratt chooses to divide by 4 to achieve the calculated density. This would seem only to be appropriate if we were looking for a formula with 2 atoms of carbon?
- Actually—by 1960 calculation—since the density of air is 14.43 times that of hydrogen gas the calculated value of the vapour density relative to this gas is 23.1. This represents a molecular mass of alcohol of 46.2 which is entirely consistent with the modern expected formulation of C_2H_5OH.

Overall, the most surprising omission for me, was the that of a reference list of elements or their symbols or their accepted 'equivalent' (combining) weights that were being used in the publication. Neither were there any formal statements or explanations of 'general' theory, such as methods of calculation, gravimetric or volumetric procedures or even standard laboratory processes (e.g., filtration, distillation, collection and drying of gases) that might by applied throughout. There is a huge number of sets of tabulated data in the various sections—particularly noticeable is the emphasis on specific gravity measurements on liquids and to estimate the concentrations of aqueous solutions e.g., of alcohol, acetic acid and potassium carbonate.

A possible explanation of my own surprise and concern for the lack of any separate, or reference, section of 'theoretical framework' may lie in the fact that I graduated with a degree that was explicitly in *PURE* chemistry. I recall celebrating the fact that it was not applied and probably not even applicable to real life. (With the possible exception of becoming a teacher of chemistry.) I could not have articulated clearly at the time why I was so keen on 'purity' nor was I aware of the, then fairly recent, split between 'science' and its applications, 'technology'. Apparently, this was caused by the abhorrence of the (mis) applications of chemistry during the first world war and those of physics during the second. The denial of applicability seemed to give *pure* scientists the intellectual and moral high-ground and leaving the responsibility for the application of science to the technologists and engineers. This issue from around 1950–70 is cogently explored in an essay by Susan Lindee, which forms Chapter 3 of Oreskes (2019) pp. 163–180.

Fuels and the materials of industry and commerce

Following on from the discussion of heat in section C above, it is interesting to examine the fuels listed for use. These are 'wood', 'charcoal', 'peat', 'coal' and 'coal gas'. The last is evaluated for its 'illuminating quality'. Marsh gas is mentioned as the 'bihydride' of carbon, which is consistent with the attribution of an equivalent weight of carbon as 6 (Section D above), although it is now known as methane—CH_4. In 1845, we are informed that Great Britain produced more coal than all the rest of the world. (Vol. 2 p. 73) From a twenty-first century perspective the very limited value accorded to petroleum seems almost unbelievable: *"In the districts adjoining the Caspian Sea where petroleum springs are abundant the inhabitants manufacture a fuel by impregnating clay with the combustible fluid; the clods are afterwards burned in an ordinary hearth. By the gradual evaporation and combustion of the carbides of hydrogen, a fire of considerable intensity results.* (Vol. 2 p. 97) This provides a huge contrast to the current global importance of petroleum and the economic and political consequences in the Middle East. Also, there is no awareness of possible widespread environmental consequences of large-scale production and combustion of coal. A further, and perhaps surprising, omission from the publication seems to be any explicit references to heats of reaction.

Throughout the whole of 'Muspratt's Chemistry' there is an emphasis on manufactured chemicals that seems unusual from today's chemistry perspective, but which reflects the importance of the economics (and, presumably global influence) of the industrial effort. The table below gives details of some of these 'unusual' topics and the number of pages dedicated to them from the 2022 total.

Topic	Pages	Number of pages	% of Total
Beer	Vol. 1, pp. 236–284	49	2.42
Bread	Vol. 1, pp. 353–391	39	1.93
Butter	Vol. 1, pp. 394–404	11	0.54
Candle	Vol. 1, pp. 404–441	38	1.88
Cement	Vol. 1, pp. 452–463	12	0.59
Cheese	Vol. 1, pp. 463–470	8	0.4
Cider	Vol. 1, pp. 473–477	5	0.25
Disinfectants	Vol. 1, pp. 556–565	10	0.49
Dyeing and Calico-printing	Vol. 1, pp. 565–781	217	10.73
Fuel and Gas	Vol. 2, pp. 1–174	174	8.61
Glass	Vol. 2, pp. 183–250	68	3.36
Gums to Gutta-percha	Vol. 2, pp. 310–366	57	2.82
Ink	Vol. 2, pp. 372–385	14	0.69
Leather	Vol. 2, pp. 491–532	42	2.08
Manure	Vol. 2, pp. 544–565	22	1.09
Paper	Vol. 2, pp. 640–659	20	0.99
Photography	Vol. 2, pp. 680–716	37	1.83
Pottery	Vol. 2, pp. 742–832	91	4.5
Soap	Vol. 2, pp. 868–893	6	0.3
Wine	Vol. 2, pp. 1106–1149	44	2.18
	Total	964	47.68

The minute detail in which industrial processes are discussed, together with an emphasis on commercial aspects: developing concern for Health and Safety

Almost half of the publication is concerned with the topics listed in the previous section. However, the strong technological bias is also found in all other sections. For example, the section on 'iron' (Vol. 2 pp. 403–457), following a general discussion of the blast furnace process, provides details of no less than 12 variants on the blast furnace exemplified from practice in countries across Europe and in America—these include the shapes and dimensions of the furnace, the nature of the reacting mixture placed in the furnace and the expected yield of iron from the ore. A great deal of detail is also given as to how the blast of air—including the development and introduction of the 'hot' blast—is produced and introduced into the bottom of the furnace.

As a detailed exemplar of an industrial chemical process I will explore the production of 'white lead'—a basic carbonate of lead ($Pb(OH)_2.2PbCO_3$)—by the 'Dutch Process'. This was described by Holmyard and Palmer (1952) in their text-book 'A Higher School Inorganic Chemistry' which I used as a student in the 1950s and as a teacher in the 1960s. I recall being surprised by the starting materials. Part of Holmyard's description (p. 334) is quoted below:

> *"The best-quality commercial white lead, in which the particles are extremely fine and which therefore has high covering power is made by the so-called Dutch process. In a brickwork 'stack' is placed a layer of horse dung or spent tannery bark. This ferments and keeps the stack warm, while carbon dioxide is formed as a product of the fermentation. On the fermenting layer are set a number of pots containing vinegar or dilute acetic acid, and perforated rolls of lead sheet are laid above them. Similar series of tannery bark, pots and lead rolls are built upon the first series, until the stack is full. … … At the end of some three months, the stack is dismantled, and the white lead is removed, washed, and dried."*

I imagined that this was a fairly small-scale process, probably carried out in the corner of a farm or tannery-yard! I was impressed to find that the scale was really substantial. A railway was provided to transport the materials, and a number of stacks constructed, one per day, such that full-time operation could be maintained over the three-month period (about 90 stacks)—each stack seems to have been about 13 ft. square and about 20 ft. high (Vol. 2 pp. 478–483).

This section also begins to show concern for the health of the operatives as can be seen from the following extract from p. 477. *"The manufacture of white lead, though of long standing, and comparatively very extensive, has been, till within a few years, very fatal to those engaged in the operations."* This is backed up by a statistic, that in the eight years up to 1844—at the *Hôpital de la Charité*—1163 patients were admitted with 'lead cholic', of whom 406 were employed in the manufacture of white lead and 385 were painters. He continues, *"It is pleasing to state, however, that endeavours are now generally made by proprietors of white lead factories to remove the causes of the frightful mortality so long produced, by adopting proper machinery for the execution of those parts of the business as prove most dangerous to the health of the workmen, and by enacting rules which enforce the observance of every precaution on the part of the employed."* Clearly this is an early example of developing effective concern for 'Health and Safety at work" with chemicals.

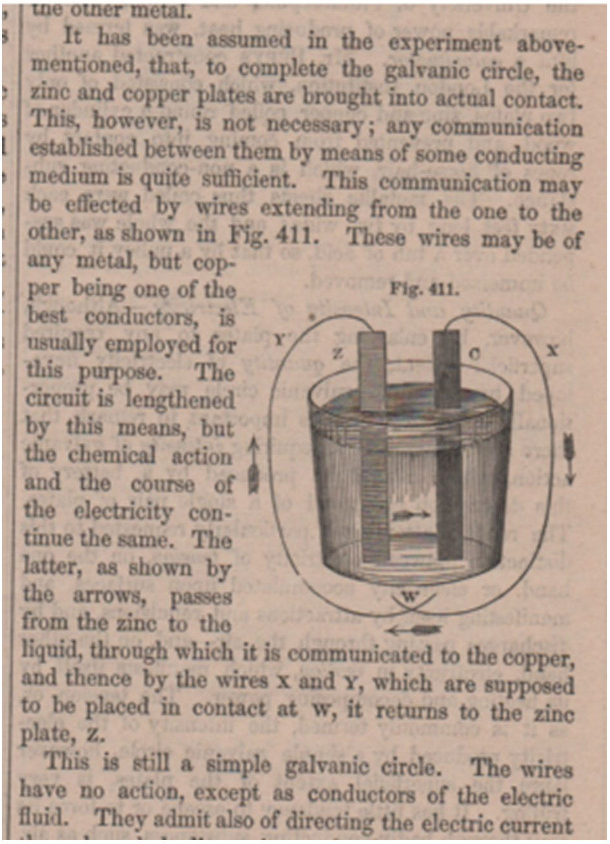
Processes in very early stages of development in 1860

Below, two processes of electrometallurgy and photography have been highlighted since they seem to provide interesting insights into the developing issues and ideas at that time.

(a) Electrometallurgy (Vol.1 pp. 762–816) *"This is the art of depositing metals from solutions of their salts, upon metallic or other conducting surfaces by the agency of voltaic electricity;"* (p. 762).

Early experiments with 'galvanism' with Galvani and Volta began around 1790–1800 and many variants of galvanic batteries were well developed by 1860. The deposition of metals from solution was practised during the early years of the 19th Century, mainly as a hobby, to produce facsimiles of coins, medals, plaster casts, leaves and insects. (Non-conducting surfaces were first covered with a thin coat of 'plumbago' (graphite).) The process was first industrialised in England by Messrs. Elkington who began silver plate operations in 1845. (www.silvercollection.it/elkington.html).

Box 3: A Galvanic Circle



the other metal.

It has been assumed in the experiment above-mentioned, that, to complete the galvanic circle, the zinc and copper plates are brought into actual contact. This, however, is not necessary; any communication established between them by means of some conducting medium is quite sufficient. This communication may be effected by wires extending from the one to the other, as shown in Fig. 411. These wires may be of any metal, but copper being one of the best conductors, is usually employed for this purpose. The circuit is lengthened by this means, but the chemical action and the course of the electricity continue the same. The latter, as shown by the arrows, passes from the zinc to the liquid, through which it is communicated to the copper, and thence by the wires x and y, which are supposed to be placed in contact at w, it returns to the zinc plate, z.

Fig. 411.

This is still a simple galvanic circle. The wires have no action, except as conductors of the electric fluid. They admit also of directing the electric current

The idea of a 'galvanic cell' was clearly developed (termed a galvanic circle) and a section from p. 783 is reproduced in Box 3. This example is also the basis for the 'Daniell Constant Battery' that was developed in 1836. Experimentation with other pairs of metals had led to the development of an early 'reactivity series' (electrochemical series) for common metals and this is given below (p. 780):

Most	Positive
1	Potassium
2	Zinc
3	Cadmium
4	Tin
5	Iron
6	Lead
7	Copper
8	Bismuth
9	Nickel
10	Silver
11	Antimony
12	Gold
13	Platinum
Least	**Positive**

However, (p. 787) states, *"It is to be observed, however, that this order is not constant with all fluids, with all acids, or even with the same acid at different concentrations."* More modern terminology is also beginning to be used (p. 792) in that *"the positive pole or electrode* (on a battery) *is that from which the electricity proceeds and is termed the* ***anode,*** *the negative pole, or that which receives the electricity, is termed the* ***cathode.*** It is important to recall that in 1860 electrons were unknown and, by convention, electric current in the circuit flowed from + to –.

It is interesting to note that the use of 'magneto-electricity' or that produced from a dynamo was perceived as quite unsuitable for use in electroplating since the necessary constancy of current could not be obtained. This was despite considerable investment at the time by Elkingtons to try to build a dynamo with a sufficiently stable current output. (A diagram is provided in Muspratt's text.)

(b) Photography (Vol. 2 pp. 689–715) Muspratt clearly felt that this process had a bright future. (p. 689) "*Of the various applications of chemistry to the arts, there is perhaps none more interesting than PHOTOGRAPHY—the art by which images formed in the camera obscura are fixed upon various tablets, such as glass, paper, metallic plates, leather, et cetera; for when it is considered that by means of suitable lenses an image may be formed of any object, celestial or terrestrial, from which light proceeds, the applications of photography appear to be unlimited, and the art assumes an intellectual character, which raises it above those other arts of civilisation that merely minister in some particular way to comfort or luxury."*

Processes for fixing images had developed over the earlier part of the century and an account of these processes is provided starting with the earlier explorations of Josiah Wedgewood (1802) and later developments including those of Daguerre and Fox-Talbot. The light-sensitive properties of silver salts were by now well known, He states (p. 696) that: "*It is well known to every chemical student that a silver salt such as the chloride, iodide, bromide, phosphate and the like, when freshly precipitated and presented to the sun's rays rapidly assumes a purplish hue and finally turns black.*"

The details provided describe and attempt to explain the processes used for capturing both positive and negative images and they imply that active photographic plates were not available commercially. Full details of the chemical recipes needed for the various processes of sensitising the plates, developing the images and fixing them are provided for use by the photographer. In any negative process where the image was initially formed on paper, it was necessary to 'wax' the paper to give some transparency to allow for the printing of a positive image from the negative. Incidentally, also in the same guidance (p. 705) *"The average time of exposure with a good light, a lens of fifteen inches focus and a half inch stop, is seven minutes."* This provides a clear insight into the difficulties of photographing anything liable to move, and into the dimensions of the cameras in use at the time.

Considering the progress yet to be made towards the ubiquitous availability of film in the mid-twentieth century for both black and white and colour photography and cinematography and when most families had at least one film camera—with the films often being taken to the local chemist (pharmacist) for processing and printing—it seems incredible that now (in the first quarter of the twenty-first century) chemistry in photography has now been largely been overtaken by digital capturing and recording of images electronically.

In conclusion

Reading these large books has provided a wealth of interesting insights into the chemical technologies of the mid-seventeenth century. The 'theoretical background' has been sparse and developed only within the separate topic sections. Perhaps inevitably considering the date of publication, there seems to be little in the way of a consistent framework of theory and calculations are frequently difficult to follow and are often based on data that are inscrutable (cannot be accessed). The world of chemistry in 1860 seems to be largely a dimension of commerce—as the chemical industry still is today. As mentioned earlier, when I graduated as a chemist in 1960 I celebrated the fact that it was a degree in *pure chemistry*, and certainly the chemistry content of my degree programme made little reference to industry, commerce or to applications and was thus, unsullied by chemical aspects of warfare. From this perspective it seems ironic that the spectacular developments in the power and utility of chemistry between 1970 and the present have been largely dependent on analytical instrumentation developed commercially and on computing power for computation and information processing As a chemistry teacher I soon found it important to link the subject into real life with my students. I am, however, grateful that I was supported by text-books that were smaller and more accessible than Muspratt's Chemistry and which were able to tell a much more coherent story of our subject from an explanatory and theoretical perspective.

Part 2: Reflections on Chemistry Education arising from reading Muspratt's Chemistry (1860)

In this section I hope to be able to provide some insight into chemistry education since 1860 and to reflect briefly on changes subsequently. It so happens that I was born exactly half way between then and now, consequently I have some experience of the latter half of educational developments during this period. Thus, I write from the perspective of a chemistry learner who began his study of chemistry almost a century after the book's publication.

I should perhaps also confess to having been 'dogged' for almost the whole of my professional career by the taunts from educational cynics that say:

> "Those that can, do. Those that can't do, teach. Those that can't teach, teach teachers!"

Since this largely represents the trajectory of my career, I strongly dispute this sentiment. However, there are other misconceptions about teaching—my main contention relates to the expectation 'in high places' is that teachers need to know all about their subject before they teach it. Having a degree in chemistry is a sufficient background to teach chemistry or even science to 16+. At a trivial level both are self-evidently true, but in my experience teaching, preparing to teach and reflecting on the results of teaching are most powerful *learning* experiences. (Goodwin 2000).

I am unable to provide any insightful perspective on the first 100 years. In 1860 it was not yet a requirement that all children should attend school and thus the ability to read and write was mostly confined to the more affluent families—and to families of clerics who were provided with a 'living' by the church. The 1870 Education Act required children to attend school from age 5–11 and by the end of the century the school leaving age had been raised to 12. Secondary education was still confined largely to the children of affluent families and inclusion of science in the curriculum was rare and variable. A full survey of science educational developments during the first sixty years of the twentieth century can be found in Jenkins (1979).

Chemistry learning in 1950/60's

Over the century following the publication of Muspratt's Chemistry seismic changes had taken place in the political, social and economic structures of Britain. The burgeoning and confident (some might say 'supercilious and patronising' or even 'bullying and exploitative') days of the British Empire were coming to an end, Éire had attained independence (as The Irish Free State in 1922 and Ireland (Éire in the Irish language) in 1937—https://wiki2.org/en/Irish_Free_State) and independence and self-government were in the air for the other British Dominions. The British Commonwealth was emerging. However, in the 1950s we were still coping with the economic and social aftermath of the Second World War (1939–1945) and having to come to terms with the atomic arms race and the cold war.

In education, by 1950, secondary schooling had become compulsory and the school leaving age had risen to 15. The 1944 Education Act had introduced the tripartite system of education for secondary education in England when, on the basis of their performance in an examination at11 + primary school pupils were allocated places at either a 'grammar', 'technical' or 'secondary modern' school as was deemed appropriate for their academic potential 'measured' by their 11 + performance.(https://www.parliament.uk/about/living-heritage/transformingsociety/livinglearning/school/overview/educationact1944/.) There was a substantial shortfall in the number of graduate science and mathematics teachers available for specialist subject teaching in schools and most of these were employed in the grammar schools. The teaching of chemistry to 16 + (O-level) examination standard was largely confined, as an option, for students in these schools. However, for many poorer families it was not considered worthwhile/possible to take up grammar school places even if offered, since the extra expenses of uniform and the fact that taking the examinations at 16 + required pupils to stay on at school for an extra year beyond the statutory leaving age. This delayed their entry to the job market to the serious detriment of the family income. Staying on beyond O-level in the 6th form to study for A-level and possible University entrance required two further years at school and even more delays to earnings. Failure at A-levels also meant that University entrance was not possible and students could find themselves at a serious disadvantage when applying for jobs and/or apprenticeships when aged 18 + .

Success at A-level did open up the possibility of entry to university to anyone regardless of economic circumstance. (I was only the second member of my extended family who graduated from university.) In the late 1950s only about 5% of the total school cohort went to university and those, like myself, who came from less well-off families had all their fees paid by Local Authorities and also received a fairly generous grant to cover living expenses away from home and the purchase of books and other study materials.

The content of the grammar school chemistry I experienced both as a pupil and at the beginning of my teaching career showed a continuing effect of nineteenth century chemistry in that a substantial proportion (between 25 and 33%?) of the 16 + (O-level) syllabus was focussed on the determination and use of the *equivalent weights of* elements, acids, bases, oxidising and reducing agents. Most of the rest of the syllabus was covered by the preparation and properties of common gases, preparation of salts and an introduction to atomic theory and bonding. Even at A-level and university all volumetric solutions were standardised in terms of 'Normality'. (A Normal solution of any solute contains one gram-equivalent of solute per litre of solution.) This *seems* to simplify calculations for volumetric analysis since $N_1V_1 = N_2V_2$ by definition. (It does, however, make for 'lazy chemists' since there is a tendency to apply the formula to the results of a titration without knowing that the equivalent weight used to make up the standard solution is the one appropriate for the reaction taking place!) I was interested to note that this terminology is still explained, although not encouraged, in at least one relatively modern textbook viz. Harvey (2000) p. 16, although the first edition of this text does go back to 1956.

These syllabi at 16 + and 18 + (O and A-levels) are essentially the same as I followed at the start of my teaching career in 1961—and reading Muspratt has made me more conscious of the power key conceptual ideas e.g., using 'molecular masses (weights!) and molar solutions' rather than 'equivalent weights and normal solutions' for volumetric analysis. It also emphasises the immense value of the explanatory power of modern chemical theory as in atomic structure, bonding, thermodynamics, kinetics, the Periodic Table, structural—3D—formulae especially in organic chemistry. Almost all of this was undeveloped in 1860 and thus highlighting the problems of trying to build a coherent picture of our chemical world without access to such a framework.

It was, in fact, the prevalence of the use of 'equivalent weights in Muspratt's' publication that reminded me of the personal efforts I had had to make to change my quantitative chemical thinking from the use of equivalent weights to formula and molecular masses. This prompted the attempt to write these papers. It will be clear from Part 1 of this paper that although I initially assumed that I understood the concept of equivalent weight it became clear that my understandings in 1960 did not provide much access to the meanings and calculations that Muspratt using in his text. Indeed, it seems to me that I was experiencing an example of the way meanings and ideas change by evolution among a 'democratic thought collective' as described by Fleck and quoted by Oreskes (2019) p. 30 when '*eventually the thought style may have changed so much that the old view is essentially unrecognisable, even indecipherable.*' *"Strictly speaking, the received never understands the thought in exactly the same way as the transmitter intended it to be understood. After a series of such encounters, practically nothing is left of the original content."* It is appropriate here to stress this point as it is often forgotten when we try to communicate with others—a central concern in education (also in diplomacy and in family and international relations.) (See Box 4, Above.) Both this and the quotations from Fleck seem to be extensions of the children's game of 'Chinese Whispers' in which a sentence is whispered it turn down a long line of players –sometimes with hilarious effect when the final message is compared to the initial one.

"When a teacher uses words or symbols to communicate with a student, it is the students' interpretation of meaning, which the student receives. Similarly, if the student replies to the teacher using the teacher's words, the teacher may believe this to be evidence that the student understands." To share understanding, substantial negotiation of meaning is required. (Goodwin (2000) p.58.) **Box 4: Negotiating Meaning**

For me a particularly significant change in conventions took place between 1950 and 1970 in the accepted sign for ΔH in chemical reactions. At school ΔH was always positive for an exothermic reaction—which seemed perfectly logical since clearly 'heat energy' was one of the products of the reaction. However, at my university, movement towards international systematisation was beginning and in physical chemistry lectures we found that, following the American convention ΔH was now *negative* for exothermic reactions (Heat was being lost from the system), although in organic and inorganic lectures it remained positive! When we questioned the inconsistency, we were told that chemists needed to be able to work with either or both since it was 'only a convention' and we needed to cope.

For me in the 1960s, many important changes were brought about by the Nuffield Science Teaching Projects—in which teachers were heavily involved in trialling the materials being developed. (https://en.wikipedia.org/wiki/Nuffield_Science_Project) Even though I did not teach in a school directly involved with trials, meeting with groups of teachers in the locality and joining the ASE (Association of Science Education) were very powerful, albeit informal, forms of professional development (CPD). I also used the publication "Chemistry: The Sample Scheme" (Nuffield Foundation. 1966) extensively in my teaching as soon as it became available. I believe it was a major influence of the Nuffield programmes that science and mathematics teaching generally became much more up to date—as well as more investigative and practical—with an encouragement for pupils to ask their own questions and evaluate evidence for answers and explanations (meaningful learning.) From a chemistry perspective this seems to have finally moved equivalent weights off the school chemistry syllabus to be replaced by relative molecular and formula weights (now masses). There also became a general acceptance that ΔH in exothermic reactions really should be considered to be negative—although this perhaps should not be blamed on the Nuffield developers.

A major strength of the Nuffield projects was the way in which teachers were involved in developing and trialling materials—not all science teachers were engaged or informed by the projects but engagement with the materials spread well beyond the trial schools and widely affected school science teaching even though most pupils did not sit examinations based on the Nuffield materials—the conventional syllabuses were affected by the developments.

Many readers may not be aware of the variety of practice that operated in English Grammar schools at around 1960 and a few summary notes may be helpful here:

- There was no national curriculum and the specific guidance available to teachers were the syllabuses published by the examination boards (Overseen by a few universities or consortia.). These syllabuses were not overly detailed and interpretation was usually based upon the teacher's analysis of past examination papers and examiners' annual reports. There were a number of different examination boards, generally based on a university or a consortium of universities—contents of their syllabuses were similar but not the same—and they mainly affected the teaching in grammar schools.
- Central government had very little involvement with the school curriculum and detailed running of schools. Responsibility was devolved largely to Local Education Authorities under the direction of a Director of Education working with the local Education Committee. The only subject that was *required* by legislation to be taught was religious education. Her Majesty's Inspectors (HMI) did inspect schools, but the time between inspections for a secondary school is estimated to be about 40 years, so it was quite likely that a teacher would be inspected by HMI never or just once during a teaching career. (LEAs had their own inspectors and advisors for their schools, but numbers and levels of involvement with schools and subject departments varied widely.)
- Teacher training for secondary school teachers was not compulsory for university graduates. It was considered that having a first degree in a subject was a sufficient qualification to teach it in school. In spite of this most intending graduate teachers first took a one-year training course in a University (PGCE). This gave the opportunity to try teaching in at least two different schools without needing to live with, or recover from, the consequences of mistakes on a long-term basis. Unusually, taking a PGCE course put at risk a qualification you already had, since failing a PGCE meant that you were no longer a qualified teacher. It was not until the 1980s that the formal training requirements for science and mathematics graduates to teach in secondary schools were finally implemented.
- There were few formal health and safety *requirements.* (Although pupil safety and personal safety were always high priority—it was not, for example, usual for safety spectacles to be worn or even to be available in school laboratories) Schools were subject to the constraints of the 'Explosives Regulations' and to checks by H.M. Customs and Excise regarding supplies of ethanol and the operation of stills that might be used to produce alcoholic spirits. Beyond that there were few restrictions regarding the purchase and use of any chemicals *for educational purposes.*

To the present day

Raising of school leaving age (ROSLA) to 16 (Enacted 1964, but enforced only after 1st September 1972). In 1965 the Certificate of Secondary Education examination was introduced as a leaving qualification aimed at pupils in secondary modern schools, most of whom left school at 15 with no formal qualification at all. This did not affect most pupils until ROSLA was enforced from September 1972. https://en.wikipedia.org/wiki/Certificate_of_Secondary_Education

Comprehensive schools: The Labour Government in 1965 instituted the largest ever expansion of comprehensive education requiring all Local Education Authorities to convert state secondary school provision to become 'non-selective' and usually each school serving a local catchment area. https://en.wikipedia.org/wiki/Comprehensive_school (A decision which seemed to be based upon political dogma rather than educational principles. I may be biased in this view since the grammar school I attended in Derby and which traced its heritage back to its foundation in 1160, was closed in this process.) Ironically, because of the time taken to organise and implement the massive organisational changes involved, more comprehensive schools were opened under the Conservative government (1970–90) even though Margaret Thatcher in 1970, as Minister for Education had by then ended the requirement to convert to comprehensive secondary schools!

The move of most state secondary education to non-selective comprehensive schools led, in 1988, to the consolidation of GCE and CSE examinations at 16+to the General Certificate of Secondary Education (GCSE) that provided a'school leaving' certificate for wide ranges of attainment in up to 7 or 8 subjects. A table of approximate equivalence of grades with previous certification is provided in the following Wikipedia reference: https://en.wikipedia.org/wiki/General_Certificate_of_Secondary_Education. Changes at 16+(A-level) were less dramatic although moves were made to complement them with more vocationally oriented qualifications at an equivalent level (National Vocational Qualifications: NVQ level 3.)

Further, and possibly even more significant changes, to the examination system were (a) the modularisation of courses, particularly at higher levels. This tended to fragment both course delivery and examinations (examination at the end of modules rather than the end of the course). (b) Course content tended to be closely specified and this limited the range of questions that could be asked in examinations—and also to make illegitimate some of the enthusiasms of teachers and interests of students since 'they would not gain marks in exams.'.

Perhaps the most significant change to compulsory education over the past eighty years came also in 1988 with the Education Reform Act https://en.wikipedia.org/wiki/Education_Reform_Act_1988, which specified in considerable detail the structural elements (subjects) of the English and Welsh schools' curriculum and enshrined the content in law. It also required that pupils are regularly given standardised tests, the results of which, at a school level, are published to assist in parental choice of school. (It is clear that such parental choice is incompatible with the previous 'neighbourhood schools' organisation and change in such a large and devolved system is necessarily slow.) Science was designated a core subject and is required study for all pupils from 5–16 with most students taking science at GCSE as a double subject. This is an issue for some schools that wish to continue with separate biology, chemistry and physics at GCSE as (more effective) preparation for A-level studies in these subjects.

From a personal perspective, initially I enthusiastically welcomed the prospect of a more uniform framework of national guidance. However, in the event, the materials provided had not been trialled or evaluated in practice and proved to be far too complex and detailed to be implemented. Subsequent rapid changes proved to be highly demotivating to many teachers, especially to those who had tried hardest to implement the new orders. The latest version of the National Curriculum orders is readily available at: https://www.gov.uk/government/collections/national-curriculum.

In 1992 an inspection regime was instituted, (https://onefile.co.uk/explore/why-was-ofsted-introduced/) overseen by the ‘Office for Standards in Education’ (Ofsted), a framework for the inspection of schools published and independent inspectors (not HMI) trained and approved to carry out inspections on a four-year cycle. The current framework is available at: https://www.gov.uk/government/publications/education-inspection-framework. Inspection reports for all schools are published and made available on the internet. In my opinion there was a tendency to focus too much on formal test and examination results and this tended to dominate the curriculum in many schools to the exclusion of meaningful learning and student/teacher interests and enthusiasms. The problem may now have been recognised?

Health and safety legislation for the use of chemicals in the workplace now applies to educational establishments too. Some of the legal implications are listed below (Association for Science Education (2020) pp. 5–25).

- Employers are required to provide safe working conditions, information and training for health and safety, and a health and safety policy.
- Employees have a duty to take reasonable care for the health and safety of themselves and others, and to cooperate with their employers in matters relating to health and safety.
- The employer can delegate functions to teachers and technicians—but in accepting such functions, employees do not become responsible in the event of an accident—The employer needs to monitor that the employee is acting within the employers’ policies.
- Risk assessments allow science teachers to undertake exciting practical activities safely. (Normally, the task of assessing the risks is delegated to the teacher although the legal responsibility remains with the employer.)

Unfortunately, this can become a bureaucratic nightmare especially since most educational employers are not scientists. It thus becomes much easier for non-standard practical-work, out of school visits, and even visits from outside experts, to be avoided rather than managed. Inevitably I believe this has led to a much ‘safer’ approach to teaching chemistry, but one that provides much less experience of using a wide range of chemicals, seeing fire, explosions and dealing with hazardous chemicals. Even in my university chemistry department it is no longer possible to find stocks of chromium VI compounds and one A-level examination board even forbids the use of phenolphthalein indicator among a long list of chemicals. Unless specific experiences are required for examination purposes there is a danger that teacher experience and expertise in handling potentially dangerous reactions and chemicals will be completely lost and students will spend even more time watching video clips on YouTube! Much opportunity and energy for valuable innovation by teachers in improving practical work, developing/perfecting demonstrations or experimenting with teaching will be (has been?) lost from even the best and most enthusiastic teachers.

Chemistry syllabuses at A-level (16–18) are now much more closely specified than in the 1960s, but the range of content has not changed much. The vast majority of the chemistry content now taught at A-level was already on the syllabus in 1960s when I was teaching in schools, although the context, key issues and applications have developed. For example, coal is no longer the major source of energy and natural gas rather than coal gas is used by our Bunsen burners; sustainability, pollution and global warming rate highly in our concerns and the manufactures of steel and sulfuric (sulphuric!) acid receive less curriculum space. The most obvious change in content has been the removal of systematic qualitative analysis from the practical requirements and more emphasis on interpretation of results of analytical procedures including IR, NMR and mass spectrometry. The huge impact of information technology on the practice of chemistry may be implied but it is not clear how it can/should reflect on learning chemistry in school.

It would be spurious to attempt to list more of the changes in chemistry during the past sixty years—many of the procedures and techniques now used routinely would have been considered impossible or 'science fiction' when I graduated in 1960. The suggestion that the sequence of the bases in a DNA molecule could be determined, or even altered in predictable ways, would have been unthinkable. (All the notes I have on nucleic acids from lectures in 1959 read "Nucleic acids have a MW of about 250,000 and are composed of polymers of nucleoids; BASE-SUGAR-PHOSPHATE. The base is either a pyrimidine or a purine.") At that time, I had no perception of their double stranded spiral structure, base pairings or their biochemical significance! Similarly, from a 1960 perspective, the current speeds of spectroscopic analysis and the minute sample sizes required would not have been believed—nor would the seemingly 'magical' speeds with which computers can search databases to provide answers.

In view of the relatively small changes in the basic chemistry ideas over the past sixty years as evidenced by A-level syllabuses it seems that developments in chemistry theory have been completely outstripped by technical developments in chemistry practice. Thus, it seems that the fundamental ideas in chemistry required by the intending chemist seem to have reached a mature and fairly stable consensus at school level. One recent publication (Bulkin 2019) suggests that all the major problems in chemistry have been solved and there are no great discoveries left. Anything really interesting is at the interfaces with biology and physics (and other sciences)—indeed chemistry, he argues, has reached a level of completeness equivalent *(almost?)* to that of mathematics and thus can be considered to underpin many other scientific disciplines. Fortuitously, Bulkin's book is also a highly personal account of a life in chemistry—like me, he became a chemist around 1960—and provides a readable account from his own perspective of many chemistry developments from this date until the present, as well as arguing (Chapter 30) the 'completed chemistry' thesis described above.

Whatever, it seems highly unlikely that there will be further fundamental shifts in chemistry ideas, even though the technology and range of applications are likely to continue development. Perhaps the major challenges relate to maintaining the interests and commitment of a sufficient number of able science students in the future. To this end education at primary, secondary and tertiary levels need to seek to be valued by the community and inspirational for the students. This will require a move beyond the focus on targets and test and examination results and an encouragement for students to find and follow their personal (scientific) enthusiasms. The curriculum must engage the intellect, allow for appropriate risk and learning by experience and explore the key applications and challenges (human, medical, environmental, and moral) to which the knowledge and skills being developed can contribute towards solving. As an example, a recent edition of Chemistry Engineering News (2020) explores this issue at undergraduate level in the context of a 'systems approach to learning' and can be found at https://cen.acs.org/education/undergraduate-education/classrooms-chemistry-part-larger-whole/98/i5. Clearly, it is of central importance that students at any stage have a positive perspective on the relevance of their formal studies to themselves, their personal interests, ambitions and to their professional development. The system is failing if/when students see courses or modules *only* as hurdles that have to be negotiated on the way to a qualification or other goal. Of course, if some of their own interests and passions can be ignited within their learning—they become more self-motivated—and are much more likely to gain lasting practical value from their studies.

Not only have chemistry and education developed between 1960 and the present day—so has our more global perspective on many issues. In 1960 most of us, if we considered it at all, thought the Earth to be an almost inexhaustible resource to supply our needs and an unfillable receptacle for our waste products. Nowadays, since human population numbers have tripled since 1960 and wild populations of many/most plants and animals have seriously declined. We are being forced to reconsider our profligate use of natural resources and our pollution of the environment. It is still a moot point as to whether our species will be able to reach a sustainable balance that will enable our continuing to be a partner in the life on our planet. More recently we have been reminded of the hidden dangers to our wellbeing of evolutionary developments in bacteria and viruses which challenge our understanding of medicines and treatment and prevention of new diseases. Chemists have a significant role to play if humans are to have a longer-term future on our planet—I doubt that Muspratt had any concern in regard to such issues. However, perhaps these new perspectives will enable more chemists to care and engage in seeking sustainable solutions together with scientists, technologists, politicians from all nationalities and varieties?

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